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NISAR L-Band SAR System Performance, Error Budgets and Calibrations

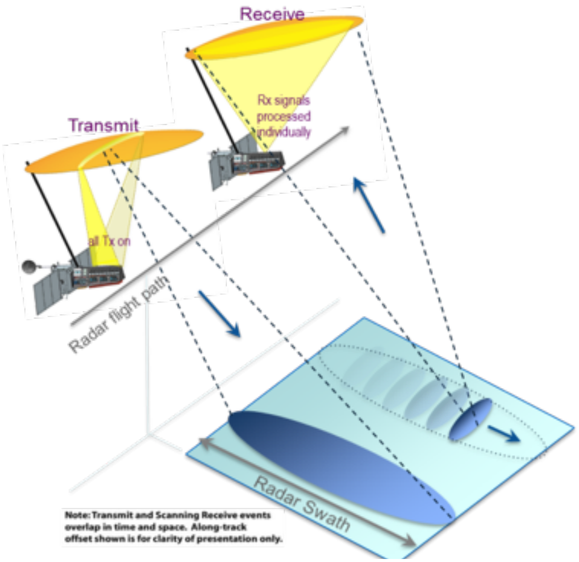
Yuhsyen Shen
Scott Shaffer, Stephen Durden, Stephen Horst
Hirad Ghaemi, Chandini Veeramachaneni

Jet Propulsion Laboratory, California Institute of Technology

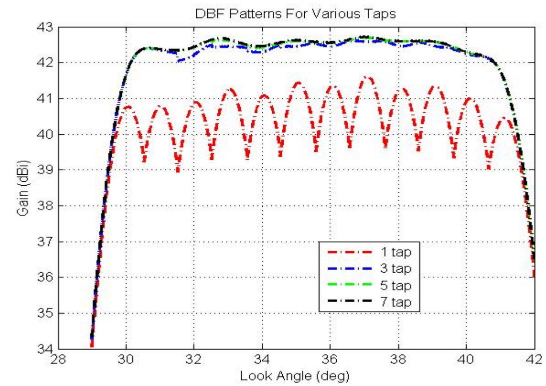
NISAR SAR Systems Implementing SweepSAR Architecture/Technique

Jet Propulsion Laboratory
California Institute of Technology

- NISAR SAR system design is based on “SweepSAR” architecture studied by JPL/DLR jointly for DESDynI/Tandem-L, which focused on wide-swath imaging capability
- The chosen SweepSAR architecture employs a large reflector with an active arrayed feed to form multiple high EIRP beams system in elevation
  - On Tx all beams are activated (transmitting) simultaneously with each beam “illuminating” a subswath and all beams together illuminating the desired wide swath, forming an effective wide antenna Tx pattern
  - On Rx the echoes are ”sweeping” over the feed, received by each T/R modules, sorted per beam echo return time/angle, followed by digital beam forming to reconstruct beam overlaps and concatenate into long echoes, forming an effective receive Rx pattern
- The system performance (in sensitivity or NES0) is dictated by having high EIRP Tx beams on Tx and well designed digital beam forming on Rx
- The SweepSAR architecture/technique
  - Provides wide-swath coverage with full azimuth integration gain, full utilization azimuth aperture (as opposed to SweepSAR for which the azimuth aperture time is divided by number of subswath)
  - Eases up dual-frequency SAR implementation by both instruments sharing the same reflector
  - Takes advantage of technologies available of light-weight compact stow volume reflector and high-efficient high power RF technologies
  - But requires more sophisticate complex high speed onboard processing and different calibration considerations



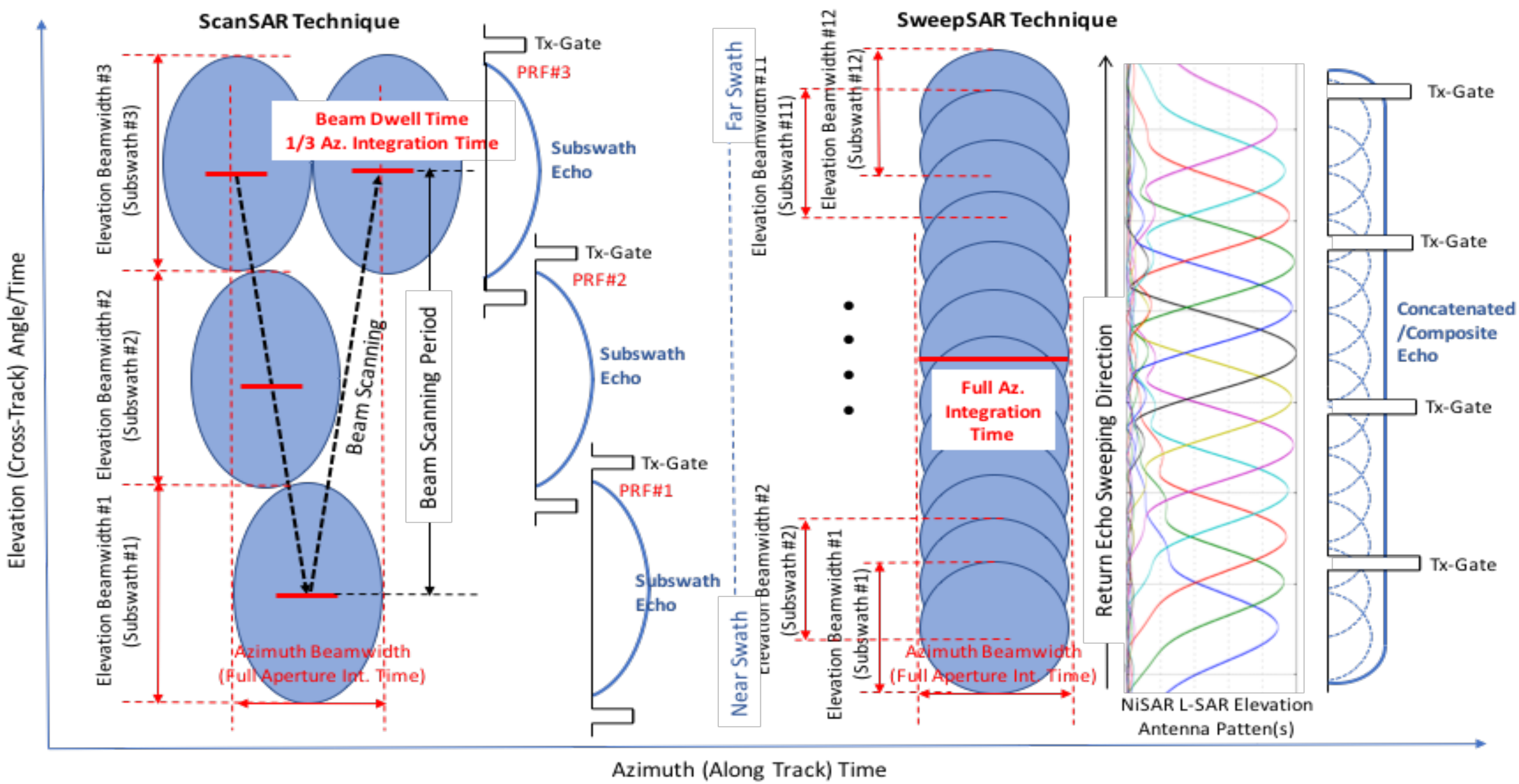
SweepSAR architecture/technique



Effective receive Rx pattern for different (1, 3, 5, 7 taps) digital beam formers

ScanSAR vs. SweepSAR

- ScanSAR electronically (by controlling the phasing of the phased array) scans a single beam in cross-track (elevation) to illuminate each subswath cyclically
- SweepSAR uses multiple sub-beams in cross-track (elevation) with each sub-beam illuminating overlapped sub-swaths for wide-swath imaging

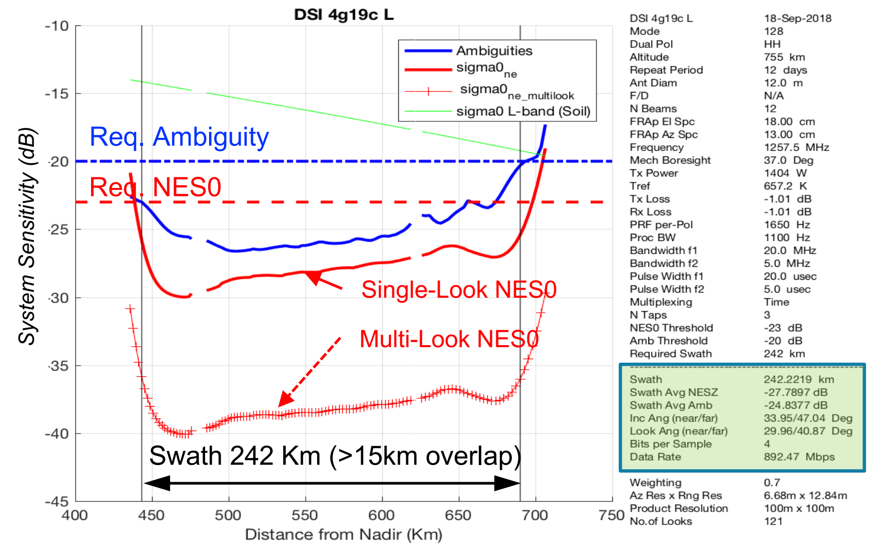


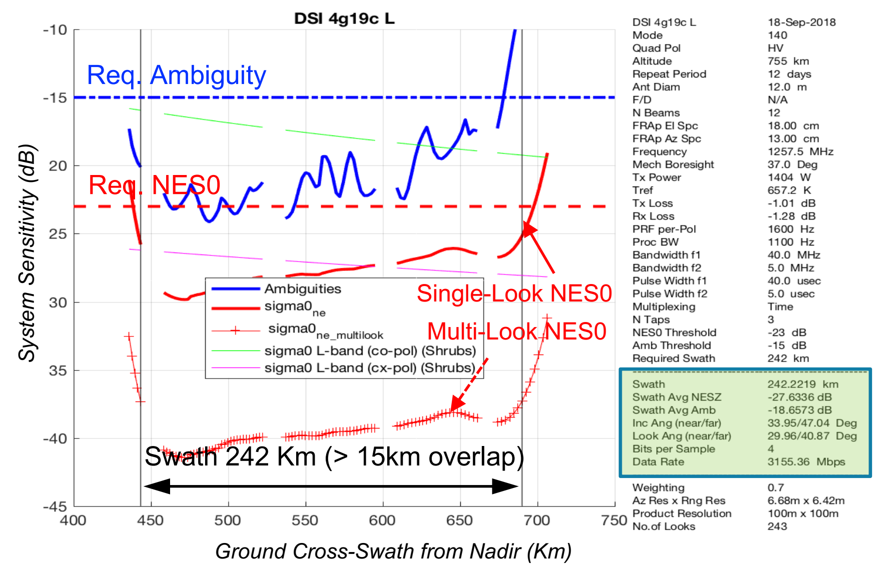
NISAR L-band SAR Design Controlled Parameters & Projected Performance (Sample Cases)

- NISAR L-band SAR System
  - Employs a 12m offset reflector with 12 dual-pol channel/beam, each consisting of a 116 W T/R model and dual-patch feed element, creating 12 1° pencil beams in elevation
  - Implements full polarimetric system that can be operated with single-pol, dual-pol, quad-pol, compact-pol configurations
  - Provides 10, 20, 40, 80 MHz waveforms with addition of 5 MHz waveform for split spectrum measurements
  - Provides PRF dithering capabilities to remove transmit gaps with slightly degraded performance

Config. 128 (Dual-Pol)	Unit	Req.	HH Beam #6 CBE
PRF	Hz	-	**1650**
Bandwidth	MHz	-	**20**
Pulsewidth	us	-	**20**
Tx power	W	1200	**1404**
Tx Gain	dBi	33.5	**33.9**
Rx Gain	dBi	40.1	**41.5**
System Loss	dB	– 2.7	**– 2.0**
System Temp	K	750	**657**
Quant Noise	dB	– 19.0	**– 20.0**
Ambiguity	dB	– 20.0	**– 24.8**
NES0	dB	– 23.0	**– 27.8**

Example: Configuration 128 Dual-Pol HH "Beam" #6 Controlled Table





Examples: Dual-Pol HH (top); Quad-Pol HV (bottom)

Definition: Resolution, Coherence, Calibration

- [Note: Spatial Resolution and ISLR assume 0.7 Hamming weighted; Coherence, Radiometric Error include multi-look for 100mx100m product spatial resolution.]
- **Spatial Resolution** (relative to ideal) is determined by system performance during one chirp and from chirp to chirp
  - Specifically, overall bandwidths plus amplitude and phase errors
- **Coherence** γ_{tot} is determined by total signal to noise.
  - Short term (random) amplitude and phase errors contributed to ISLR, reducing coherence

$$\gamma_{tot} = \frac{1}{1 + SNR^{-1} + \Sigma\, MNR_i^{\ -1}}$$

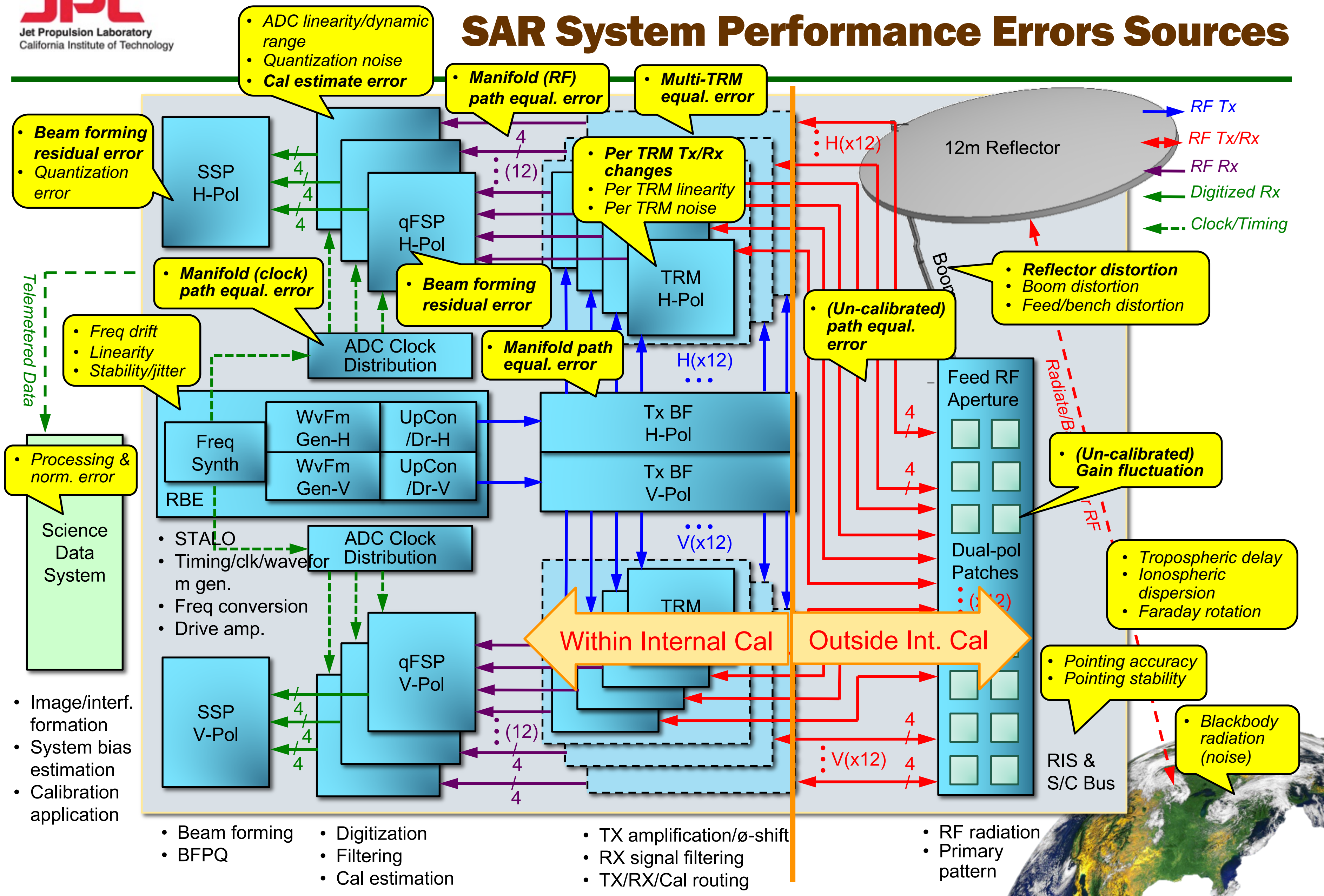
- **Radiometric Resolution** $Ksrr$ is measurement uncertainty (precision)
  - Backscatter dependent – cannot be calibrated out but can be re-estimated
  - Can be improved with higher EIRP and/or averaging more looks
  - Short term (random) amplitude and phase errors contributed to ISLR, worsening the radiometric resolution

$$K_{srr}(\mathrm{dB}) = 10\mathrm{Log}_{10}\left(1 + \underbrace{\frac{1}{\sqrt{N_{looks}}}\left(1 + \frac{1 + \frac{\mathrm{SNR}}{\mathrm{MNR}}}{\mathrm{SNR}}\right)}_{K_{pc}(\mathrm{linear}) = \frac{\Delta\sigma_0}{\sigma_0}}\right)$$

$$\mathrm{MNR}^{-1} = \mathrm{ISLR}_{rg} + \mathrm{ISLR}_{az} + \frac{1}{\mathrm{AMB}_{total}} + \frac{1}{\mathrm{QNR}}$$

- **Post-Calibration Error (Uncertainty)** Kpr is the residual errors after calibration, including amplitude and phase errors, attributed to short-term and long-term stabilities/drift
  - Estimated from the stability of assemblies and how well those changes are being monitored and can be removed
- **Radiometric Error** is RSS'ed of radiometric resolution ($Ksrr$) and calibration residual error (Kpr).

SAR System Performance Errors Sources



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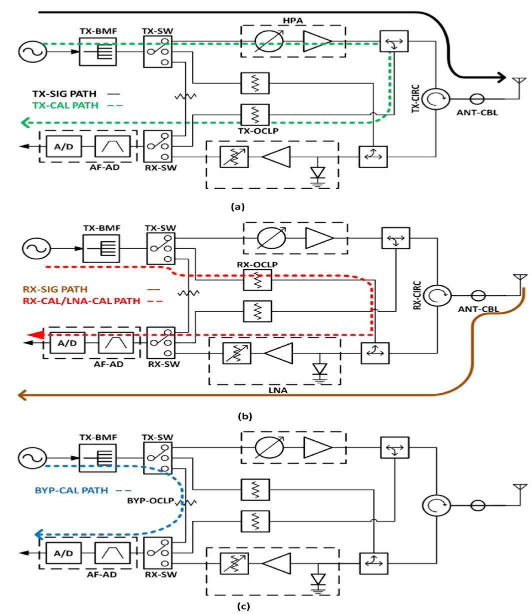
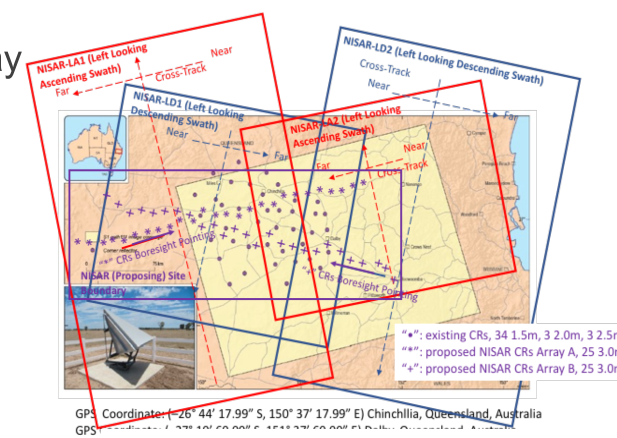
Internal Calibration Implementation and External Calibration Plan

- Post-calibration error *Kpr* refers to residual errors (uncertainties) after systematic biases have been removed. The use of internal calibration with external calibration is to determine those biases and bias changes.
- For SweepSAR system having Tx manifolds (1:12 Tx distribution) and Rx manifolds (12:1 Rx combination), non-equality/non-uniformity among channels would be minimized before flight, but those may change in flight
- **Internal Calibration:** Each TRM includes Tx, Rx, Bypass Cal paths to allow for injection of chirp/tone to:
  - Perform on-board estimate of each channel (tx/rec mag/phase) and include those estimates in the radar meta data
  - Evaluate changes between channels; if changes exceed a pre-determined value, apply correction/adjustment to the channels
  - Still has residual error in onboard estimate and correction
- **External Calibration:** Use processed images over corner reflector array site and known homogeneous target areas to:
  - Determine system bias (against the true RCS) over the entire swath
  - Assess system bias changes, in particular for the part of the system (radar antenna) not in the internal cal loop
  - Determine radar antenna pointing error and change
  - Determine polarimetric channel imbalance/cross-talk
  - Still has residual error in measurement uncertainties associated with corner reflector (background+noise) and homogenous area (*Ksrr*)



NISAR L-band TRM Cal Paths



Proposed CR Array Cal Site

NISAR L-band SAR Projected Performance and [Post-Cal] System Errors

Requirements	Req.	CBE (at CDR)	Source
Swath-avg'd NEs0 (SP/DP/QP) [1]	≤ – 23 dB	**– 25.4 dB**	Model
Swath-avg'd ambiguity (SP/DP) [1]	≤ – 20 dB	**– 24.3 dB**	Model
Swath-avg'd ambiguity (QP) [1]	≤ – 15 dB	**– 16.0 dB**	Model
Swath-avg'd co-pol radiometric error [2]	0.9 dB	**0.71 dB**	RSS'ed A &B
A. Random co-pol error (Ksrr)	0.50 dB	**0.50 dB**	Model/Measured
B. Sys. co-pol cal error (Kpr)	0.75 dB	**0.51 dB**	Stacked Up
Swath-avg'd cx-pol radiometric error [2]	1.2 dB	**1.15 dB**	RSS'ed A & B
A. Random cx-pol error (Ksrr)	0.79 dB	**0.82 dB**	Model/Measured
B. Sys, cx-pol cal error (Kpr)	0.90 dB	**0.78 dB**	Stacked Up
Systematic Phase error	3.0°	**2.5°**	Stacked Up
Coherence [3]	0.85	**0.86**	Model/Measured
Azimuth resolution broadening [4]	< 15%	**< 0.5%**	Measured
Slant range resolution broadening [4]	< 10%	**3.9%**	Measured
Swath overlap at equatorial crossing	> 10 km	**>15 km**	Model

[1] Worse case estimated values over modes (configurations) and polarization against the mode-targeted backscatters.

[2] Swath-averaged with multi-look weighted processing, post-calibration; A is target dependent

[3] Swath-averaged; combined SNR/AMB with TRM measurements of mag/phase ripple and jitters.

[4] % broadening against weighted single-look theoretical; include mag/phase contributions

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